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(Zusammenhang Zwischen Belastung durch Physikalische Umbebungsfaktoren und Zuverlaessigkeit)

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RELATIONSHIP BETWEEN STRESS DUE TO PHYSICAL ENVIRONMENTAL FACTORS AND HUMAN RELIABILITY

(ZUSAMMENHANG ZWISCHEN BELASTUNG DURCH PHYSIKALISCHE UMGEBUNGSFAKTOREN UND ZUVERLÄSSIGKEIT)

by

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Z. Psychol., 184, 1, 51-62 (1976)

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AUTHORS' SUMMARY

Physical disturbance tests are used to demonstrate an application of the analysis of reliability with reference to experimental data.

During 30- and 120-minute stressing by whole-body exposure to vibrations of different frequency, acceleration, and type, performances were required of subjects, which require them to muster all their power of mental concentration (modified clock test of Mackworth and audible signal detection experiments).

Data analysis of reliability of response proves to be a suitable means of describing performance. The results indicate that the following are the main factors affecting reliability of performance:

- condition of training of the subject;
- time of activity;
- time density of assignments;
- degree of stressing by exposure to vibrations.

An attempt is made to correlate performance, physical disturbance, and central-nervous-system activation.

LIST OF CONTENTS

		Page
1	INTRODUCTION	3
2	METHODOLOGY	3
	2.1 Tasks	3
	2.2 Experimental design	4
3	RESULTS	4
4	DISCUSSION	6
References		7
Illustrations		Figures 1-7

1 INTRODUCTION

Factors of the working environment, *ie* physical and chemical conditions to which people are exposed at their place of work, must be included as activity-specific conditions among the components of human performance which reduce reliability. To some extent occupational hygiene standards take this state of affairs into account. They regulate by law both the permissible intensity of exposure and the permissible duration of these factors relevant to occupational hygiene. Here it should be noted that observance of standards is intended not only to prevent damage to health but also impairment of performance. Such performance-related limits are, for example, a constituent of the occupational hygiene standards for the limitation of stresses caused by noise, climate and mechanical whole body vibration. DDR Standard TGL 22312 "effect of mechanical vibrations on man" lays down performance related limits for activities which make "...great demands on alertness...".

A survey of the international literature (summarised by Grether[1] and M. Metz[8]) shows that impairment of visual, motor and sensory motor processes occurs, for mainly biomechanical reasons, during and in consequence of the effect of mechanical whole body vibration. Numerous tracking investigations, tests of visual performance especially visual acuity, and delicate motor activity confirm these observations: they also represent a quantitative relationship between the degree of impairment of performance and the physically defined vibration stress. In addition there are isolated references to effects on performance due to vibration which cannot be explained by biomechanical effects, or not completely so. These appear to include activities in situations of vigilance requiring a high degree of alertness[8]. It is not impossible that changes of such dynamic components are provoked by shifts in the central nervous activation position due to the effect of whole body vibration[2].

The need for further experimental investigations is apparent not only from the findings on such unspecific effects of mechanical whole body vibration hitherto inadequately substantiated in the literature, but also by the above-mentioned establishment of performance-related limits in occupational hygiene standards.

2 METHODOLOGY

2.1 Tasks

To test the possible influence of whole-body vibration on alertness, two tests were used before, during and after exposure:

- clock test modified by Mackworth[6]
- acoustic signal detection experiments.

The results of the clock test only will be reported here. In this opto-motor test 60 lamps are arranged in a circle on a pale green display measuring 38 × 38 cm. They light up successively in an uninterrupted sequence, each lamp for 0.33 second. We define the omission of one lamp lighting up as the critical stimulus. The proportion of critical to uncritical stimuli is 1:19; the timing and location of the critical stimuli is random. A 5-minute test section therefore contains 855 uncritical and 45 critical

stimuli. The discovery of a signal is acknowledged by the test subject with a reaction button. Performance is characterised by reaction times and errors of the first and second type, *ie* signals not detected and so-called 'false alarms'. The technical experimental set-up can be seen in Fig 1*.

In addition to the conventional statistical processing of the data we subjected the recorded errors of the first type to a reliability analysis. Definition of these errors took place after checking the distribution of all test values (reaction times). The result was a normal distribution with outsiders, outsiders being defined (Sachs[14]) as all values beyond the range $\bar{x} \pm 4$ seconds. In our case all reaction times of ≥ 0.75 second were defined as errors of the first type. The reliability function R(t) was calculated (according to Reinschke[12]) over the error distribution in the test sequence with the aid of the failure rate (t).

In order to avoid performance in the clock test being affected by visual acuity impairment due to vibration, we tested under exposure conditions whether it was possible to discriminate between critical and uncritical stimuli. Results confirm that this discrimination is definitely assured even during vibration.

2.2 Experimental design

The various test series were organised according to balanced, very varied plans. Details can be gathered from the research reports of Meister and Metz[7] (1973, 1974). Independent variables were frequency of vibration (2-32 Hz), acceleration (falling below, maintaining or exceeding the limit values of Category II of TGI 22342), type of vibration (sinusoidal vibration and vibration with *stochastic frequency and amplitude* distribution) as well as duration of exposure (30 and 120 minutes). The chronological sequence of the tests is shown in Fig 2.

Twenty-one healthy male subjects aged 18 to 27 years took part in the tests. The test subject combines of the various series were normalised by means of their performance in training tests (without vibration stress).

3 RESULTS

The primary aim of the experiments was to examine and pinpoint the occupational hygiene standards to limit the effect of mechanical whole body vibration. When the standard values were maintained, and even occasionally below them, there was evidence of statistically significant impairment in performance of the tasks selected by us to test alertness, in comparison with the control conditions (without vibration). Exceeding the limit values led to significant loss of performance almost throughout. These standard related findings are described in detail by Meister and Metz[7] (1973,1974). However, we wish to stress again here the usefulness and need for psychological experiments in matters of standardising occupational hygiene.

Now for some results of the reliability analyses which provide evidence not only on the effect of the working environment condition vibration, but also on other components determining reliability.

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* The technical experimental set-up was designed by Ing. Waldau.

(1) In the area of subjective performance conditions the effect of the state of training on reliability was tested. In order to achieve a stable performance level before the start of the exposure tests and also to normalise the groups of test subjects according to their performance, all subjects took part in eight training tests of 1 hour each in which both tasks had to be fulfilled in the same chronological sequence as in the exposure tests. The learning-dependent improvement in performance, depicted in the training tests as exponential function over the training period, shows in the reliability analysis as increasing reliability with increasing duration of training (Fig 3). This variable is usually not controlled in investigations known to us in similar situations; as a rule subjects are not trained. In our opinion there is a risk here of falsifying effects superimposed by learning, which are solely interpreted as a change in long-term attentiveness.

(2) A further component of the range of subjective performance prerequisites is change dependent on time. As is to be expected, reliability in performance declines as a function of the duration of the activity. The reliability function was calculated for a 30-minute section of the 3-hour control test (without vibration) with trained test subjects. The increased drop in reliability towards the end of the test period is clear (Fig 4). This result contradicts the typical performance cycle in vigilance situations first found by Mackworth[6] and later numerous other authors (*cf* Neumann and Timpe[10]) which is that the marked initial drop in performance observed in the first half-hour is followed by stabilisation until about the end of the third hour. In complex observation situations performance does not diminish until a considerably longer period has elapsed[9,13]. It is also well known that the frequency of the signal has a decisive effect on the performance cycle[4,16]. Hence the distinct drop in performance in the first 30 minutes is found when signals are presented rarely (*cf* Neumann and Timpe[10]).

(3) In the area of the structure of the task we tested the influence of task density on reliability.

The density of the task was varied in two separate test series of 3-hour activity under control conditions (without vibration). In the first series the clock test only was set; each 5 minutes of activity was followed by a 5 minute rest. In the second series the signal detection test was set in this interval, *ie* 3 hours of uninterrupted activity can be compared with that interrupted by breaks. Here it should be pointed out expressly that the demands to be compared in the clock test are identical in both situations.

Reliability of performance is better in low task density (135 signals in 30 minutes) than in high (225 signals in 30 minutes) - see Fig 5. These findings agree with the results of Schmidtke[15] who found a reversed u-shape relationship between frequency of signal and performance. While the highest quality of observation is seen in his experiments at approximately 100 signals in 30 minutes, it diminishes at greater frequency of stimulation. The author interprets this as reaction to a situation of excessive demand.

(4) The results of the reliability analysis as a function of the additional physical interference from the working environment are shown in Figs 5 and 6.

As expected, vibration also proves to be a factor affecting reliability in the sense that under additional vibration stress of higher intensity greater impairment of reliability of performance is shown compared with the control condition.

Fig 5 summarises the last two results of the reliability analysis. The upper part contains the reliability functions at low task density, the lower part at high density. In each case vibration of the stated physical characteristic - in each case it is the permissible limit for an exposure of 2 hours - leads to a decrease in reliability of performance compared with the control condition without vibration.

Fig 6 summarises the results of the 30-minute exposure tests. It is clear that reliability depends on the intensity of vibration: the higher the vibration stress (exceeding the standard values), the greater the reduction in reliability of performance.

4 DISCUSSION

The results presented at first refer exclusively to values determined by performance, *ie* results. Negative effects of the above conditions on reliability can be interpreted as changes conditional on stress - that is negative stress effects. In itself the conclusion from performance data on stress effects is not compelling. After all, the definition of reliability assumes judgment of the 'aptness' of the task and the situational conditions. For this reason Timpe[17] demands that reduction in reliability should not be interpreted as a stress effect unless a simultaneous reduction in performance premises is proved or a correlation between effort and reliability can be established.

We consider that interpretation of the reduction in reliability during exposure to vibration as an effect of stress is justified, for the following reasons:

- The subjects were highly trained before the start of the exposure tests so that learning-dependent change in reliability can be excluded.
- The tasks were identical in the control and exposure tests compared in each case.
- The reduction in reliability due to the length of activity was operative both in the control and exposure tests.
- Additional data raised in the subjective estimation of increasing onerousness due to exposure to vibration (assessment of the difficulty of fulfilling the task on a 5-stage rating scale) indicate in our material that reduced reliability is linked with the increased effort experienced.

Shifts in the central nervous activation state might be assumed as a possible cause of loss of performance due to vibration.

Hörmann[3], Hasan[2] and Provins[11] discuss, with regard to the effect of environmental conditions (noise, vibration and raised environmental temperatures) a connection, hypothetical as yet, between the degree of actual impairment of performance and central nervous activation, although so far the functionally effective paths are not known in detail, nor is direct evidence available by means of experimental control of the activation level. We can support these assumptions of a general action mechanism of physical environmental factors on performance regulated by the central nervous system by means of our material; here is an example.

When mechanical whole body vibration was distinctly below the standard values, *ie* very low intensity, the reaction times in the clock test actually show an improvement in performance compared with the control condition without vibration, but at high vibration intensity a distinct drop in performance. With due caution one may assume that

- a distinct drop in performance occurs conditional on the duration of activity under the control condition for the tasks we use (low density),
- on additional physical stress of low intensity this drop is arrested, *ie* the activation position is shifted to a more favourable range,
- on additional physical stress of high intensity, a shift towards the overactivation pole is at the root of the drop in performance.

These results are collated in Fig 7.

At least partial verification of this suspected relationship is the subject of further work which we hope to achieve with the inclusion of physiological variables to determine the amount of effort. This would enable not only more general statements to be made on the effect of stress due to the environmental vibration factor, but also indications to be derived on general unspecific effects of factors of working environment on performance, and finally this would open up means of predicting performance under adverse conditions and solving practical problems of occupational hygiene standardisation on a theoretically higher plane.

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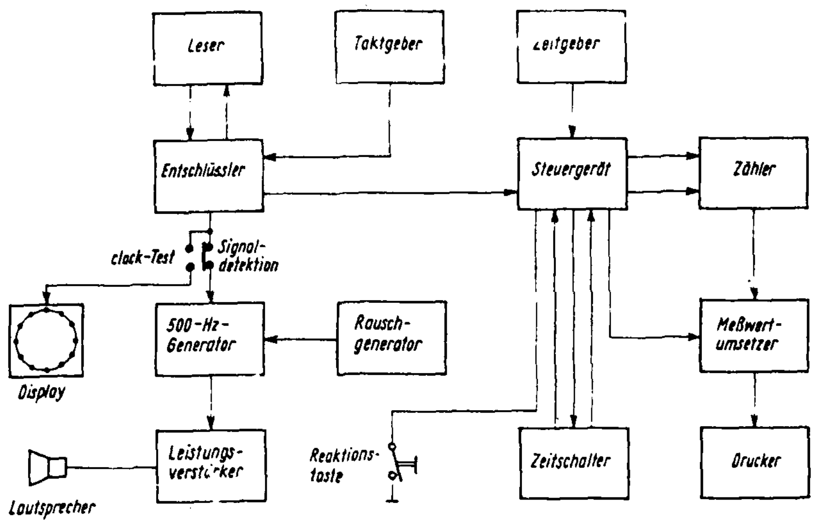
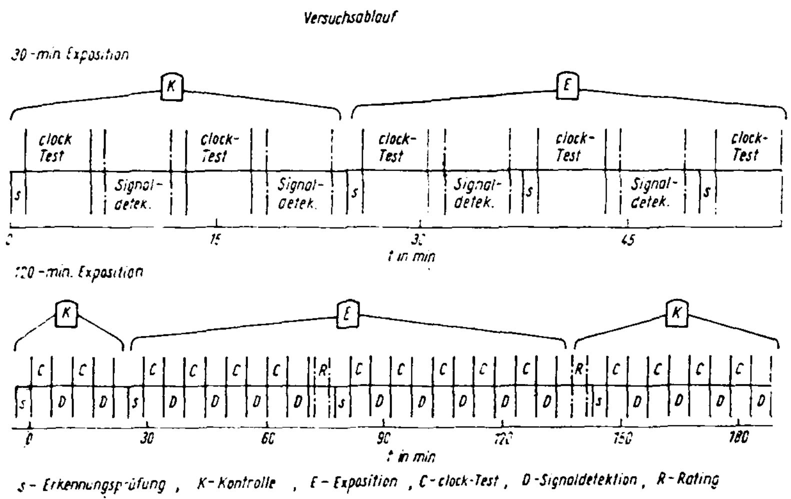


Key:

Leser = reader
Taktgeber = impulser
Zeitgeber = timer
Entschlüssler = decoder
Steuergerät = operating mechanism
Zähler = counter
Rauschgenerator = noise generator

Messwertumsetzer = data converter
Lautsprecher = loud speaker
Leistungsverstärker = amplifier
Zeitschalter = time switch
Drucker = printer
Reaktionstaste = reaction knob

Fig 1 Block diagram of test set-up



Key:

Erkennungsprufung = recognition test
Exposition = exposure

Fig 2 Test sequence with 30 minute and 120 minute exposure. s marks the test of discrimination of critical and uncritical stimuli

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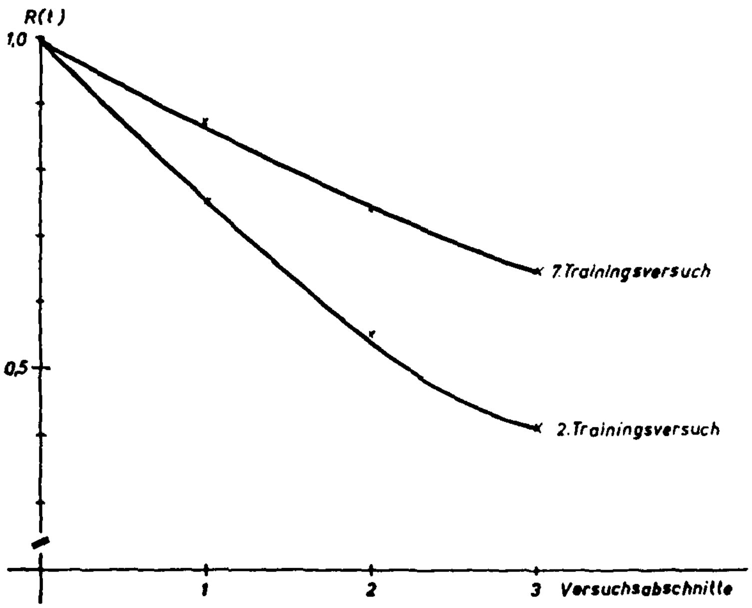


Key:
Versuchsabschnitte = test sections

Fig 3 Reliability of performance depending on training condition (control tests without vibration)

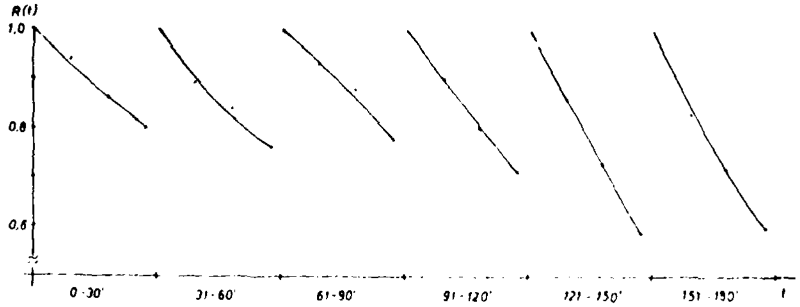
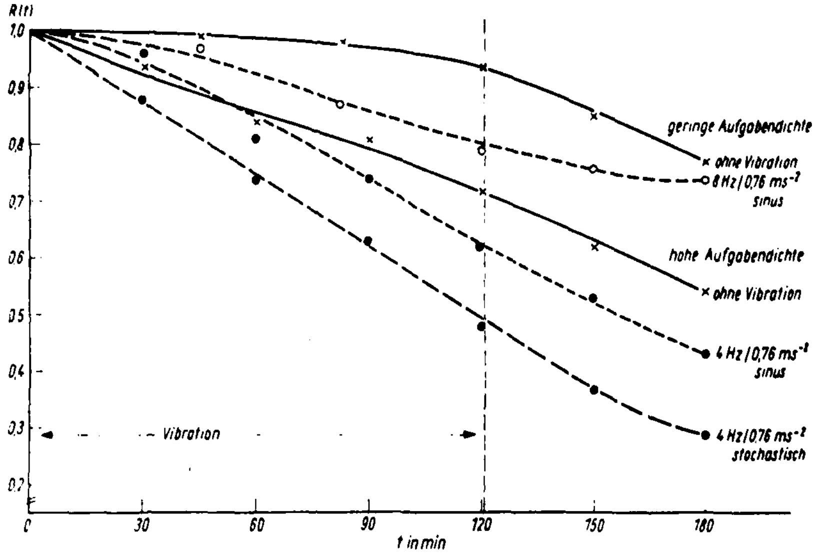
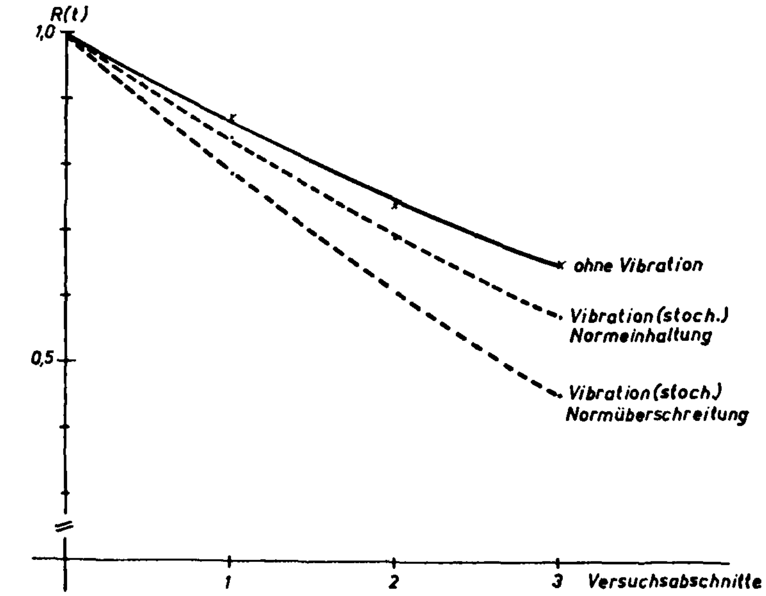


Fig 4 Reliability of performance depending on duration of activity (control tests without vibration)



Key:
Geringe/hohe Aufgabendichte = low/high task density

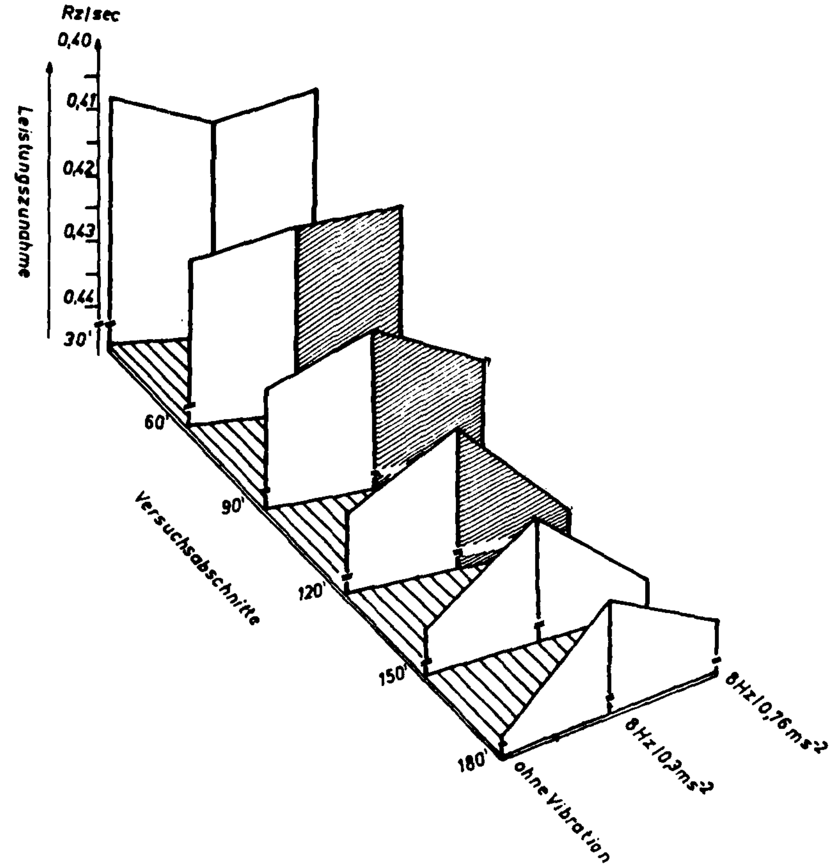
Fig 5 Reliability of performance depending on density of tasks and vibration stress. The solid lines show the reliability function under control conditions (without vibration) in high and low task density. The dotted curves show the reduced reliability values due to vibration in different forms of vibration which in every case conform to the permissible limits for 120 minute exposure.



Key:
Normeinhaltung = adhering to standard
Normüberschreitung = exceeding standard

Fig 6 Dependence of reliability on the degree of vibration stressing during 30 minute exposure

Fig 7



Key:
Leistungszunahme = increase in performance

Fig 7 Mean reaction times for detected critical stimuli during 180 minute activity (low task density) and 120 minute vibration. The planes from back to front show the duration of activity. The measuring points side by side in one plane from left to right mark performance in the control test (without vibration), where vibration is distinctly below the limit and where the limit is adhered to for a 120 minute exposure. The hatched areas indicate exposure to vibration.

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